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THE EVOLVED EXPENDABLE LAUNCH VEHICLE (EELV) STANDARD INTERFACE SPECIFICATION FOR SPACE VEHICLE ACCOMMODATIONS

Frank L. Knight¹

Abstract

The Evolved Expendable Launch Vehicle (EELV) system is being developed by the United States Air Force (USAF) and its prime contractors to meet the nation's need for expendable launch vehicles through the year 2020. While the USAF is sharing the funding of the development of the EELV to meet the US National Mission Model, it is expected that the EELV will also have the capability to satisfy requirements for commercial launch vehicles. The EELV system will then be a national resource that will be used in a large percentage of the expendable launch vehicle missions in the first part of the next century. Therefore, the provisions of EELV for space vehicle accommodation will be of great importance in designing the next generation of spacecraft. These provisions are specified by the EELV "Standard Interface", which is being developed by the US government in cooperation with the EELV contractors and spacecraft suppliers.

The purpose of this paper is to describe the development of the EELV Standard Interface Specification (SIS) and its implications for spacecraft designers. The approach taken in the development of the SIS is described and a synopsis of the major technical parameters in it is provided. These parameters include the mechanical and electrical interfaces, provisions for spacecraft commanding and monitoring, space vehicle environments, and launch site processing.

Introduction

EELV Objectives

The EELV system will be the United States' newest family of expendable launch vehicles. The United States Air Force is funding the development of the EELV in response to the President's National Space Transportation Policy to develop a cost effective alternative to current expendable launch vehicles for the National Mission Model of government payloads. It is also expected that the EELV will be marketed for commercial and international payloads.

The primary objective of the EELV program is to reduce the cost of space transportation while retaining the capability of current launch vehicles (Delta II, Atlas II and Titan IV). The goal is to reduce the cost of launch by 25 to 50 percent, using current systems as a cost baseline. In order to meet this objective, an acquisition strategy was adopted which implements the acquisition reform principles established by former Defense Secretary Perry in 1994.¹ This innovative strategy, as described by Steele and Portanova², emphasized the government's desire to move away from the traditional "oversight" role of the Air Force to one of a "trusted partner" in the development of EELV.

EELV Schedule

The program began in August 1995 with the awarding of four contracts for the Low Cost Concept Validation (LCCV) phase of the program. During LCCV, Alliant Techsystems, Boeing,

Lockheed Martin, and McDonnell Douglas developed their basic EELV concepts over a 15 month period, which was concluded with a “down-select” to two contractors. In December 1996, contracts were awarded to Lockheed Martin and McDonnell-Douglas (now Boeing) for the Pre-Engineering and Manufacturing Development (Pre-EMD) phase of the EELV program. The Pre-EMD phase of the program is 17 months long and was to conclude with the selection of a single contractor for the Engineering and Manufacturing Development (EMD) phase of the EELV program. However, on 6 November 1997, the USAF announced a change to the acquisition strategy which permits the awarding of two contracts for the development phase of the program.³ The EMD phase will begin in June 1998. The first launch of the Medium Launch Vehicle (MLV) EELV is scheduled for 2001, and the first Heavy Lift Vehicle (HLV) in 2003.

Standardization Goals

One of the keys to the affordability of the EELV system identified in the Operational Requirements Document⁴ is standardization. This applies to many facets of the EELV program: infrastructure, equipment, and processes for launch vehicles, facilities, pads, and payload interfaces. The payload interface is a particularly important item with respect to reducing the cost of space transportation. It is imperative that a “standard” interface be developed which will both accommodate existing payloads and provide a robust capability to designers of future satellites. A standard payload interface avoids the need to have a particular payload “tagged” to a particular launch vehicle and allows for flexibility in switching payloads among launch vehicles. It also eliminates many of the costly, mission-unique integration tasks which add to the overall cost of current launch vehicles. It will be particularly important in light of the new EELV acquisition strategy, since only with a standard interface can payloads be easily swapped between the two competing versions of the EELV system.

Standard Interface Development

In order to develop the EELV Standard Interface, the Standard Interface Working Group (SIWG) was formed. The SIWG consists of all the various EELV stake-holders, including the EELV system program office (USAF and The Aerospace Corporation), the launch vehicle contractors, the system program offices for the military space vehicles (SVs) that will fly on EELV and their contractor representatives, and representatives from commercial spacecraft manufacturers. In the spirit of acquisition reform, the SIWG worked as a team to mutually define what type of interface would best be compatible with the various launch vehicle (LV) design concepts and accommodate both existing and future payloads. The government team led the discussions, but depended on the contractors to share information and resolve conflicts between rival concepts, even in the context of a competitive contracting environment.

Early in the LCCV phase the basic concepts of the payload interface were developed in mutual agreements reached by the SIWG. In order to provide a structure for these agreements, this author developed a draft “Standard Interface Specification” (SIS) to more logically order the interface provisions being developed by the group and provide a framework for further development of the EELV payload interface. Since then the SIS has been further developed, and has become a contractual requirement for the EELV program. The current version of the SIS⁵ is being used by the two remaining EELV contractors in developing their detailed launch vehicle designs prior to the beginning of the EMD phase of the EELV program. The development of the SIS was accomplished with two over-arching goals in mind:

1. Reducing the cost of launching space vehicles (SVs) into space.
2. Providing users with a capability as good or better than current launch vehicles.

Therefore, the EELV SIWG philosophy has been to provide an equivalent (or better) performance and SV accommodation capability to the SV users while at the same time ensuring that the SV payload environments and launch environments are equivalent to (or less severe) than the LVs currently used to launch military SVs. This “no worse than” policy includes the Delta and Atlas LVs for MLV spacecraft and the Titan IV LV for HLV spacecraft. The accommodations provided by other current launch vehicles were also considered and taken into account wherever possible. The needs of commercial SV busses were also considered, in recognition that military payloads may use commercial busses in the future and that commercial viability is important to the overall cost reduction goal.

Standard Interface Provisions

The interface provisions described in the SIS define a minimum capability which is provided as a standard service to payloads which will fly on the EELV system. The SIS also defines the worst-case flight environments for the SV. These environments are defined at the Standard Interface Plane (SIP), which is the interface between the LV and the SV. Unlike with previously developed LVs, the SIP is not the SV separation plane. This approach was taken because many existing spacecraft will require an adapter to fly on EELV, whereas SVs in development may be designed to attach directly to the SIP. These concepts are illustrated in Figure 1. The major provisions for SVs are described in the following sections. The SIS describes these provisions in more detail.

Mechanical Interface

As a standard, the LV supplies one of two standard mechanical interfaces (one for the MLV configuration and one for the HLV configuration). This interface joins the LV to the spacecraft or the payload adapter, as provided by the payload user. For the MLV, the bolt pattern has a 62.01” diameter, whereas the HLV interface has a 173.00” diameter bolt pattern. The surfaces will be flat to within 0.015 inch for MLV, and to within 0.030 inch for the HLV.

The volume available to the payloads is specified in terms of the maximum spacecraft dynamic envelope as shown in Figure 2. For HLV, this envelope is similar in size to that for the Titan IV envelope, as shown in Figure 2a. Two sizes of standard fairing envelopes have been defined for MLV, as shown in Figures 2b and 2c. The nominal fairing envelope size is as shown in Figure 2b. When the SV does not require the nominal size, a smaller fairing envelope (similar to the Delta II envelope) shown in Figure 2c may be substituted at the option of the LV contractor. The SV center of gravity restrictions for SVs are shown in Figure 3. Note that in addition to the HLV and MLV, this figure also references an MLV-S, which is a smaller version of the MLV booster used for lighter SVs. This is also true for SV minimum stiffness requirements which are shown Table 1.

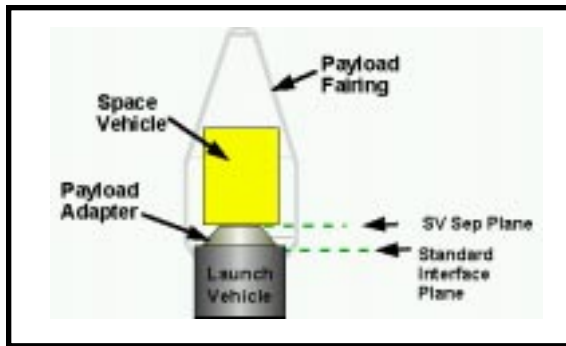


Figure 1 -Standard Interface Concepts

EELV Vehicle Class	Fundamental Frequency (Hz) (including adapter)	Axis
MLV-S	12 30	Lateral Axial
MLV	8 15	Lateral Axial
HLV	2.5 15	Lateral Axial

Table 1- SV Stiffness Requirements

Electrical Interface

Electrical connections from the LV to the SV are provided through the Standard Electrical Interface Panel (SEIP) which is shown conceptually in Figure 4. Twelve twisted pair circuits are available for SV power on the launch pad, with each circuit carrying up to 11 amperes. These circuits are connected to payload-provided ground equipment, which is supplied with 120- or 208-volt power from the launch facility. In addition, 60 twisted-pair circuits which may carry up to 3 amperes are provided. These circuits may be used to monitor SV bus voltage, battery temperatures, battery pressure or other payload health measurements as required by the SV.

Eight redundant pairs of command lines are provided which can be configured as 28 volt discretes or switch closure functions. The LV will be capable of accepting two channels of serial data from the SV at the SEIP for interleaving into the LV's telemetry stream to the ground. The maximum combined data rate of both channels is two kilobits per second.

Electromagnetic compatibility between the LV and the SV is assured by using allowable emissions and susceptibility curves which have been tailored from MIL-STD-461C.

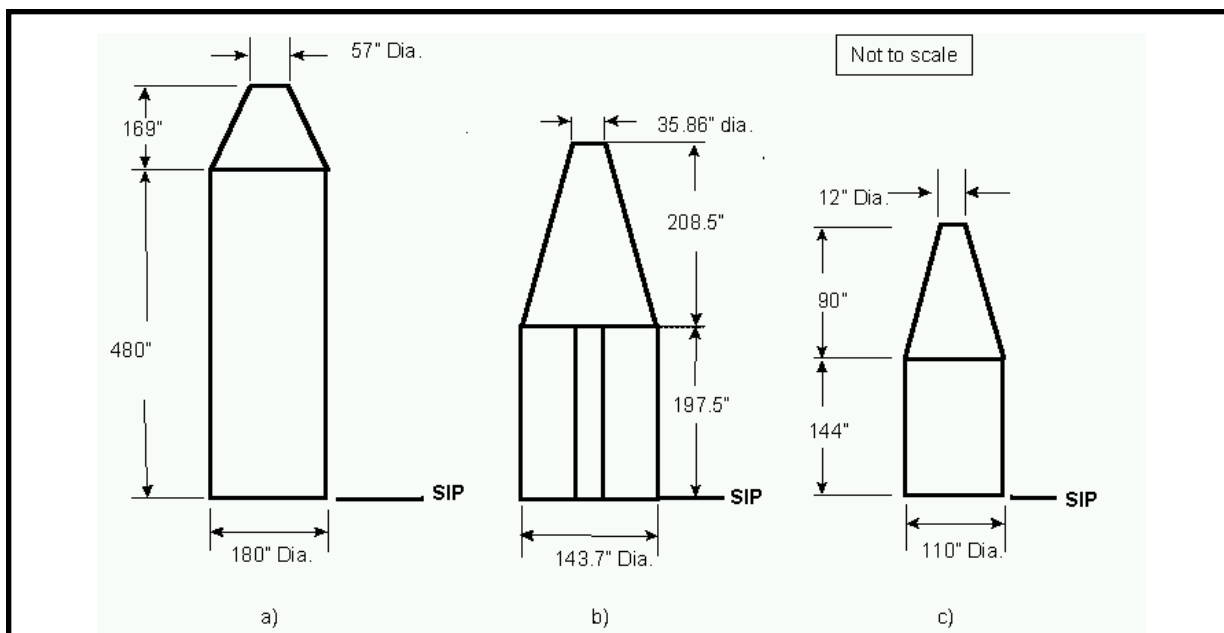


Figure 2 - Spacecraft Dynamic Envelopes: a) HLV b) MLV c) MLV small

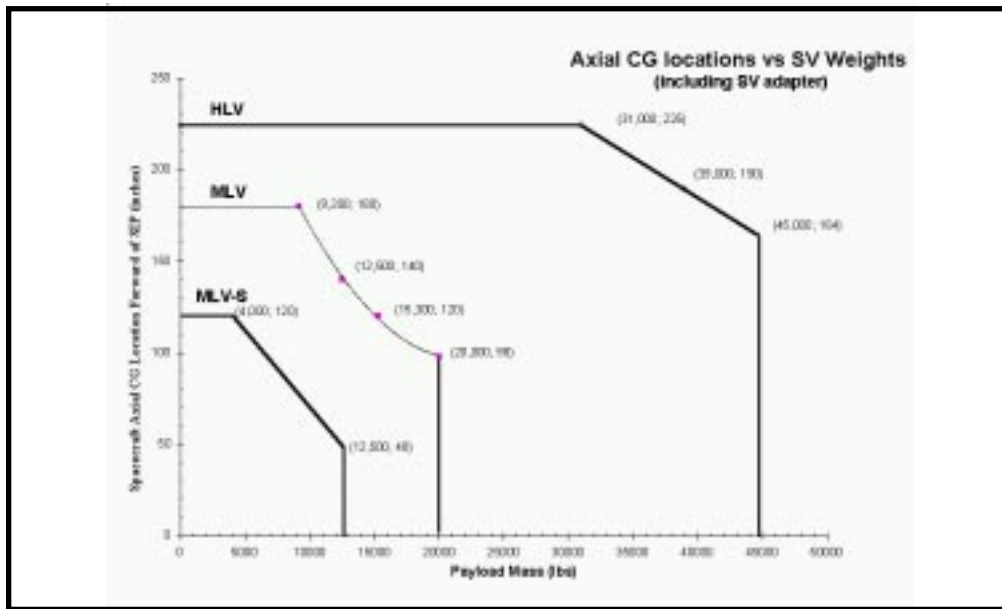


Figure 3 - Allowable CG -Locations (non-spinning payloads)

Fluid Services and Air Conditioning

EELV provides air conditioning to the SV while it is encapsulated in the payload fairing, and has the capability to divert up to 40% of the air flow to temperature-sensitive items such as spacecraft batteries. The inlet temperature of the air conditioning will be controllable to 5 degrees over a range of temperatures of 50-85°F. Cleanliness is guaranteed to be Class 5000 or better. In addition, the launch facility will have provisions for a nitrogen purge capability, up to 500 standard cubic feet per hour, for sensitive SV instruments.

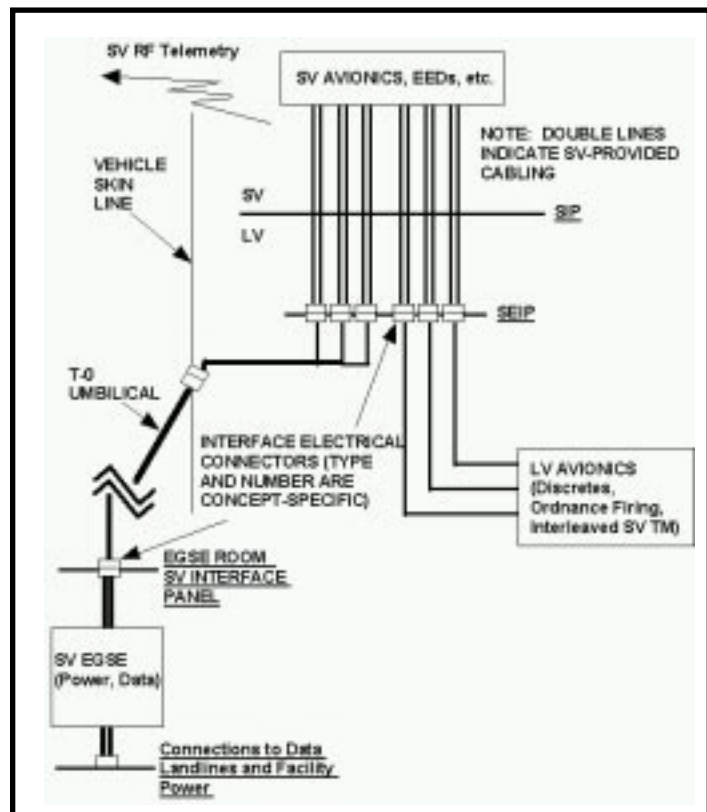


Figure 4 - Interface Wiring Harness Connections

Space Vehicle Environments

The environments experienced by the SV during launch have been designed to not exceed the present fleet of launch vehicles. Thermal environments vary greatly depending on the mission parameters, but the maximum total integrated energy specified in the SIS will not exceed that caused by the fairing temperatures shown in Figure 5. The maximum instantaneous free molecular heating on spacecraft surfaces perpendicular to the velocity vector at the time of fairing separation is 320 Btu/hr-ft².

Protection from contamination after payload encapsulation is such that the particulate contamination levels from the launch vehicle are not to exceed 1% surface obscuration from payload encapsulation through orbit insertion. Molecular contamination levels are less than 150 angstroms over this period.

Preliminary center-of-gravity acceleration values for the calculating loads at the standard interface are shown in Table 2. These quasi-static load factors are given for specific SV weights, and must be adjusted for other SV weights according to steady state acceleration vs. weight curves which are concept-specific, and are still under development.

The maximum predicted sound pressure levels (value at 95th percentile with a 50% confidence) from liftoff through payload deployment are shown in Figure 6. This graph shows one-third octave band sound pressure levels versus one-third octave band center frequency for a typical SV with an equivalent cross-sectional area fill of 60 percent. SVs with a larger cross-sectional area than 60 percent will incur higher acoustic levels. The maximum shock spectrum at the SIP (value at 95% probability with 50% confidence; resonant amplification factor, Q=10) is shown in Figure 7.

Payload fairing internal pressure decay rates are limited to 0.4 psi/sec except for a brief transonic spike to 0.6 psi/sec for the HLV version of EELV. Decay rates for MLV are limited to 0.3 psi/sec except for a brief transonic spike to 0.9 psi/sec.

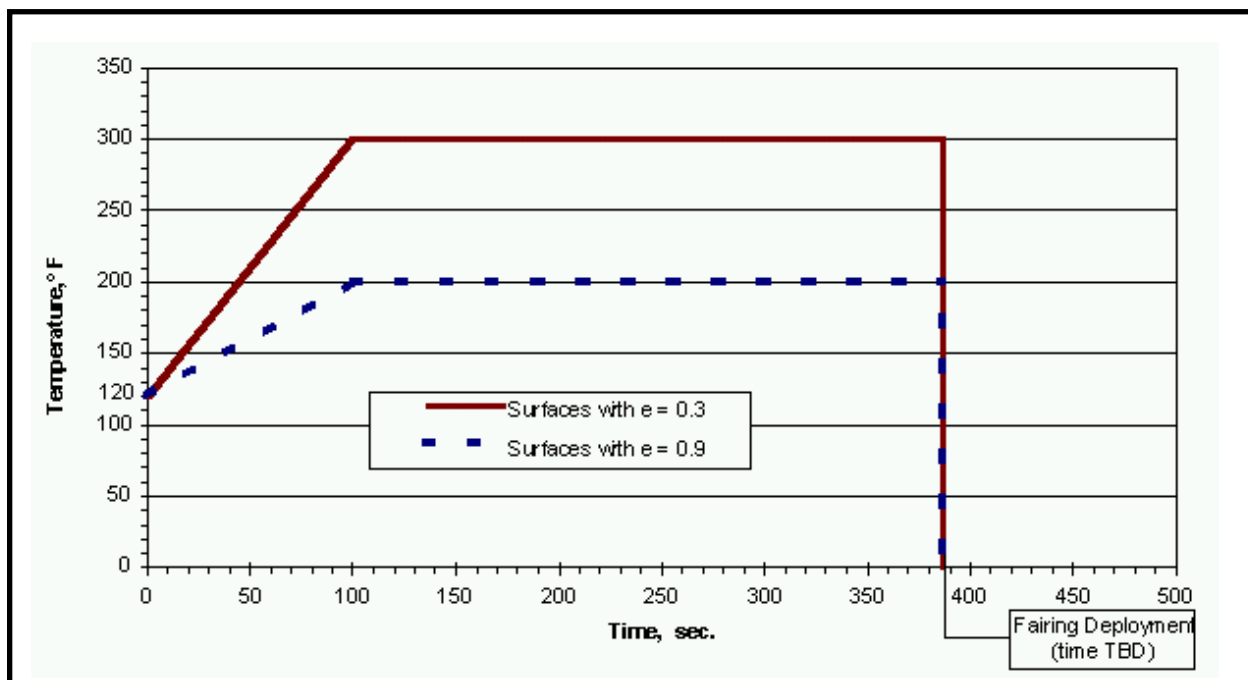


Figure 5 - Maximum Payload Fairing Surface Temperatures

Vehicle Class	Vertical G's	Lateral G's
MLV-S (@ 2000 lb.)	7.2	± 0.5
	3.5	± 2.5
	0	± 2.5
	-1.5	± 2.0
MLV (@ 6000 lb.)	6.5	± 0.5
	3.5	± 2.0
	0	± 2.0
	-1.2	± 2.0
HLV (@ 10,000 lb.)	6.0	± 1.5
	3.0	± 2.5
	0	± 2.5
	-2.0	± 1.5

Table 2 - Quasi-Static Load Factors

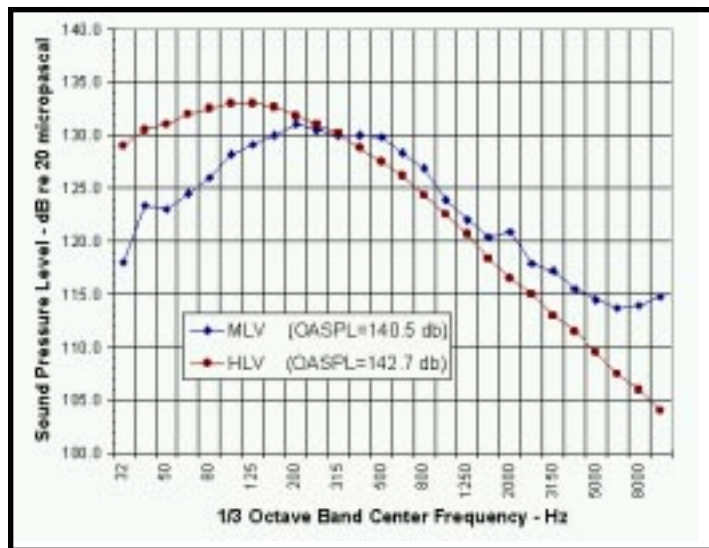


Figure 6 - EELV Acoustic Levels

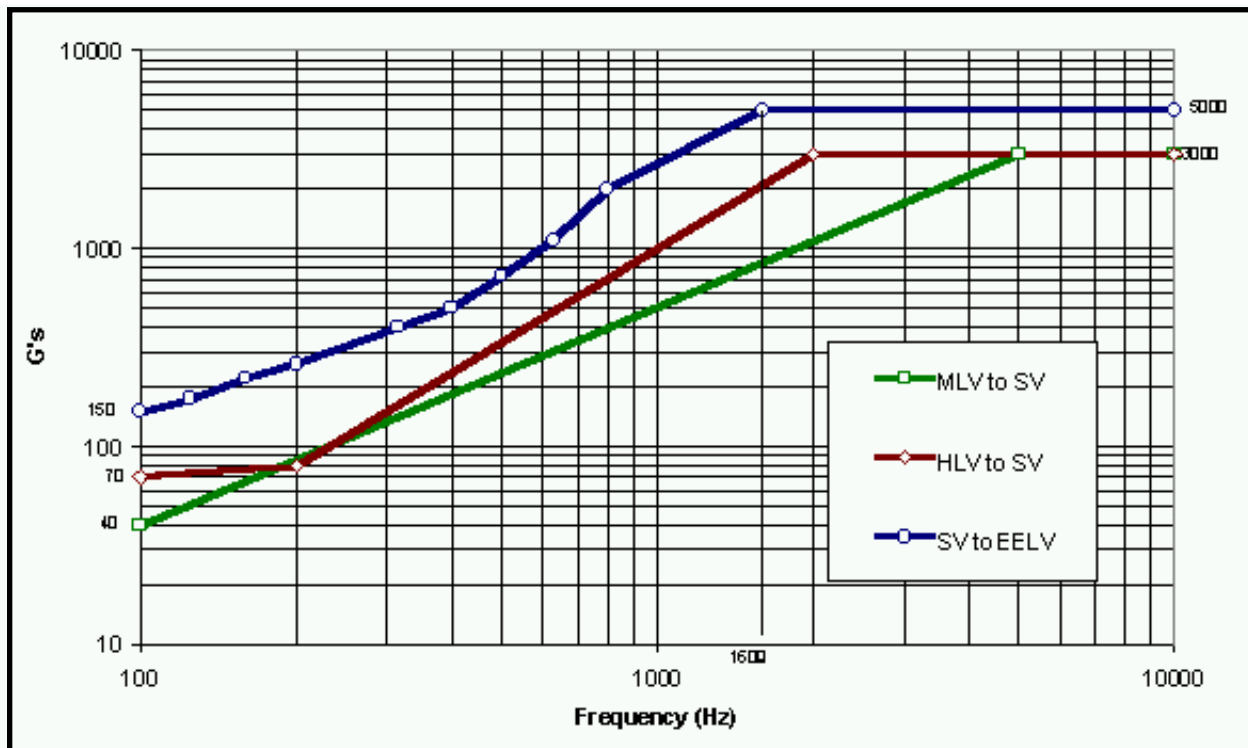


Figure 7 - EELV Maximum Shock Levels

Acknowledgments

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